CCD Based Multi-Wavelength X-ray Diffractometer

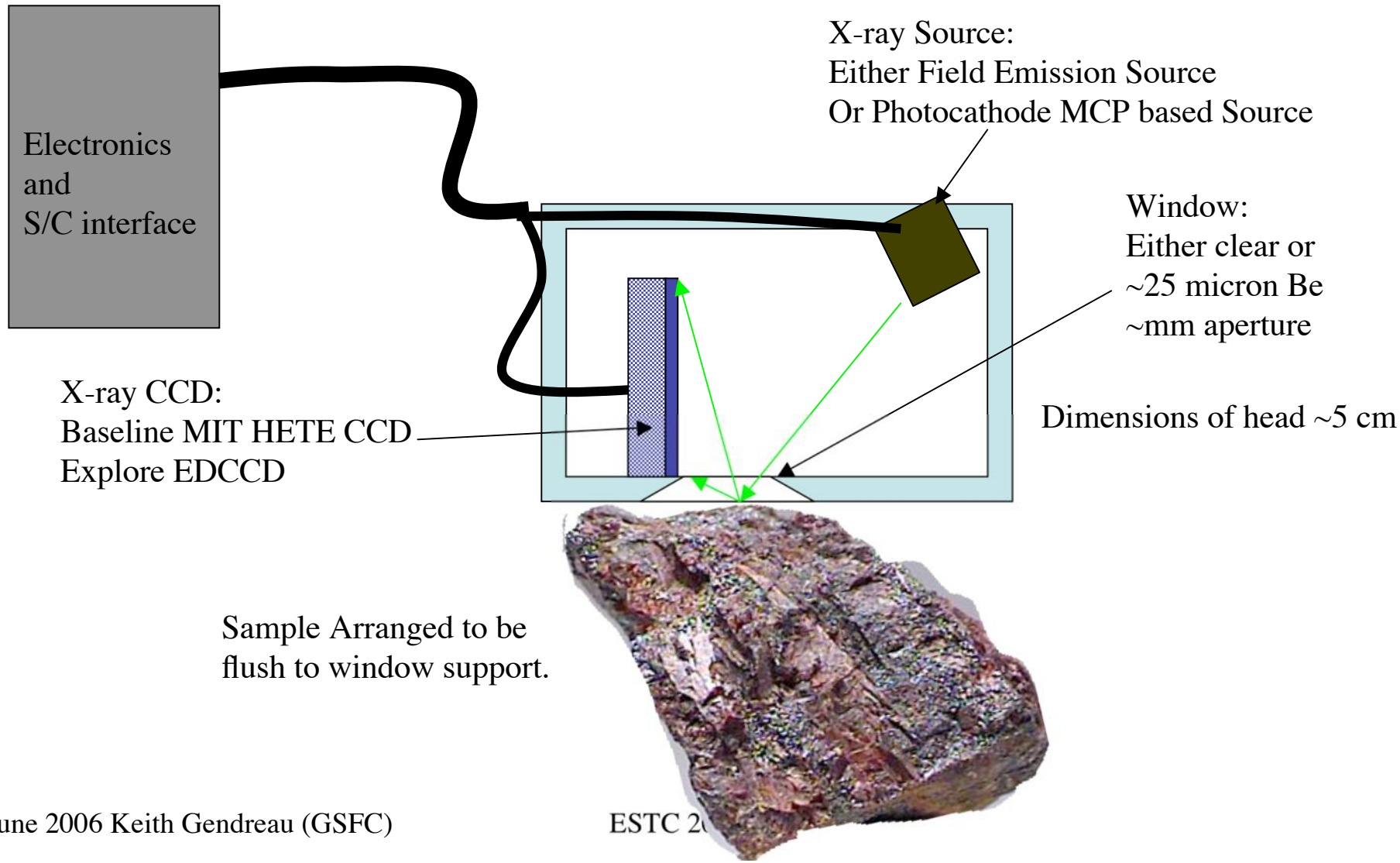
Keith Gendreau (GSFC), Zaven Arzoumanian (GSFC), Vanderlei Martins (GSFC), Rosemary Millham (OSU, SP systems), George Ricker (MIT), Peter Ford (MIT), Richard Starr (GSFC), Jack Trombka (GSFC)

Looking to expand

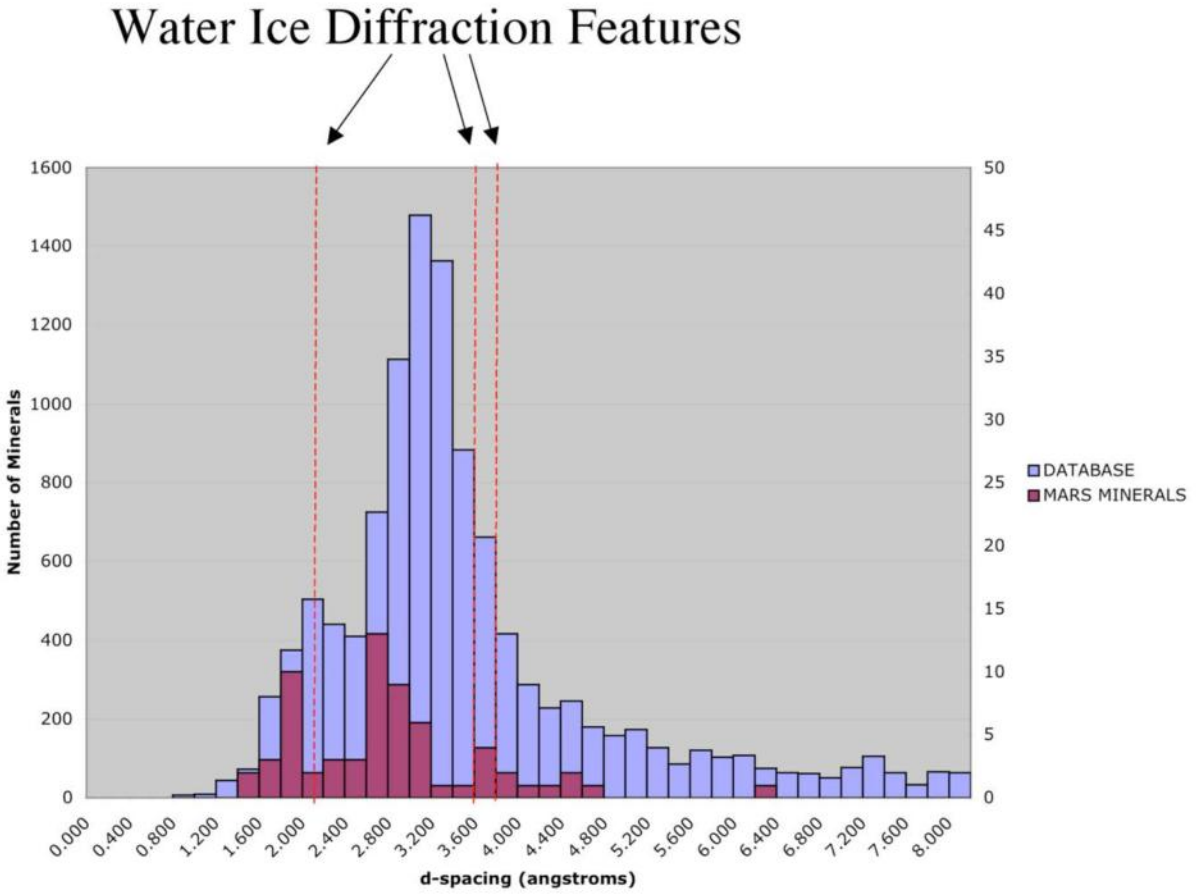
The Concept (for NASA Missions)

- A combination X-ray Diffractometer/ Fluorescence instrument that requires NO sample preparation
- Definitively identifies minerals, including water ice.
- Provides particle/grain sizes, shapes, and orientations -> clues to formation history
- Based on flight proven X-ray CCD technology
- Has option to study aerosol mineral composition

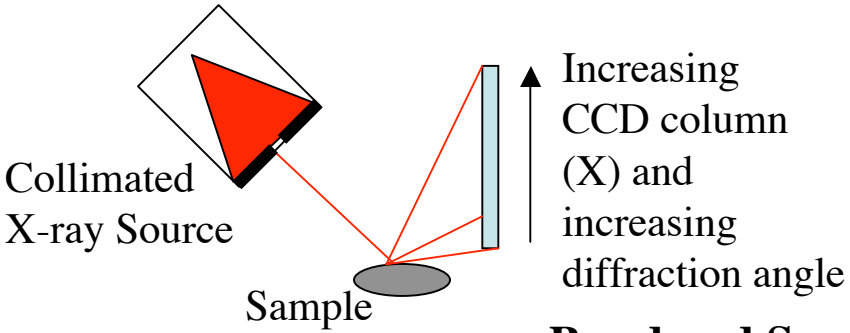
Implementation



Application to VSE and Lunar Exploration

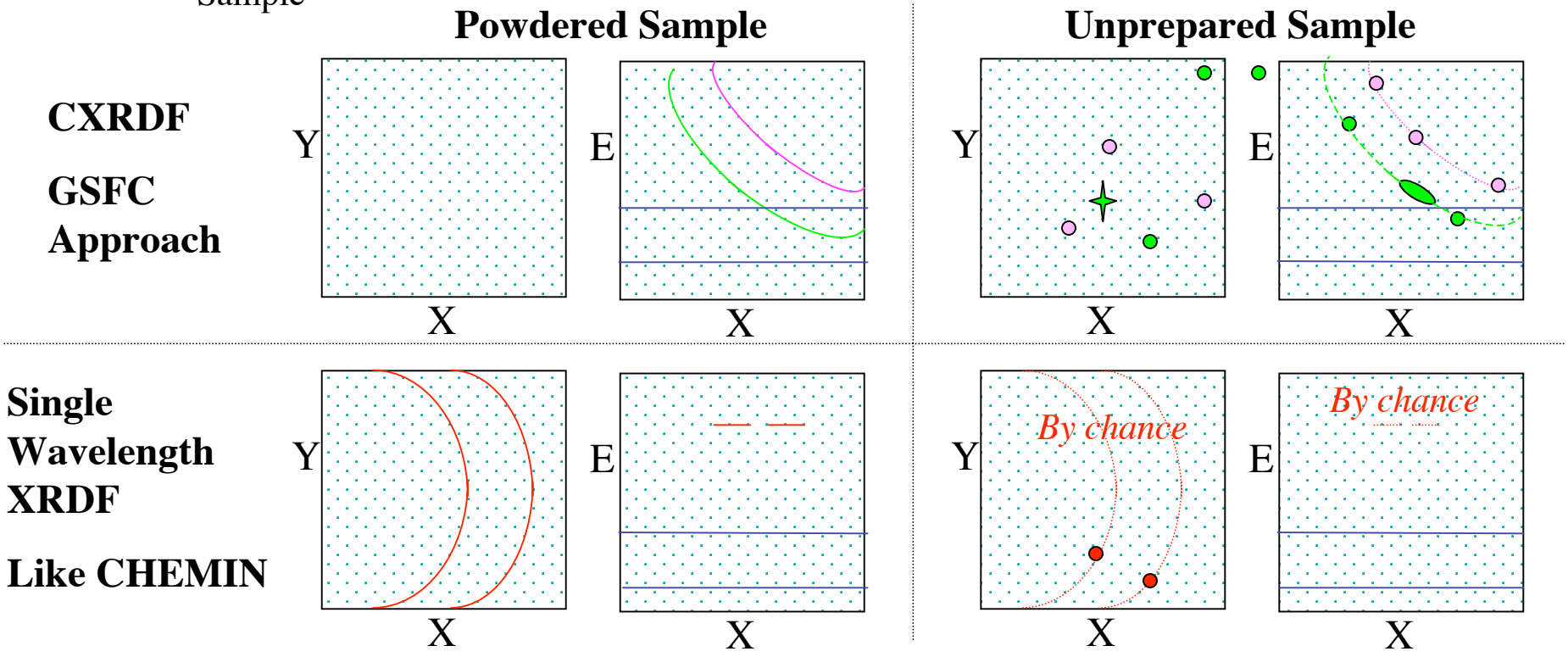


Not the same as CHEMIN



λ=12400 eVÅ/E(eV)
θ=Geometric function(X)
nλ=2d sin(θ)

GODDARD SPACE FLIGHT CENTER

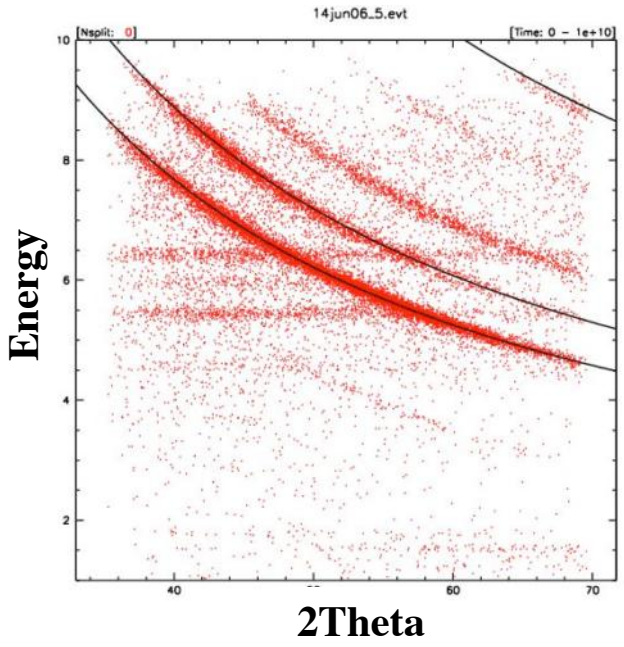


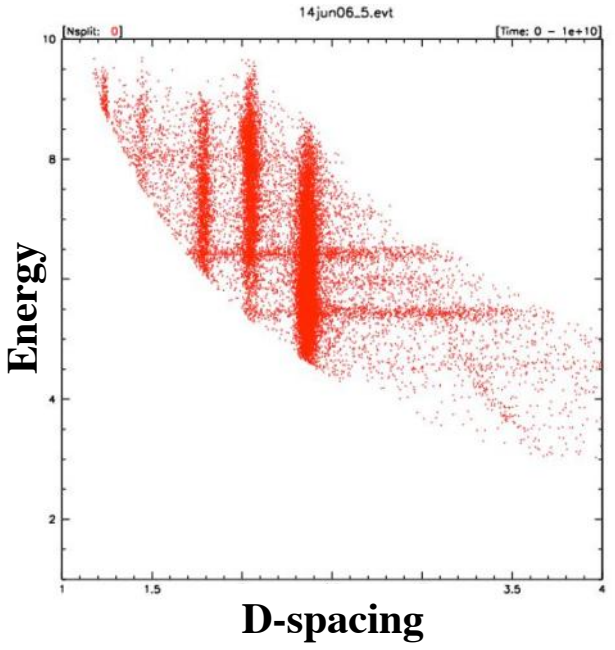
Our new concept expands X-ray diffraction into a new dimension.

Prototype Data (Al 6061)

ODDARD SPA
E FLIGHT CEN
ER

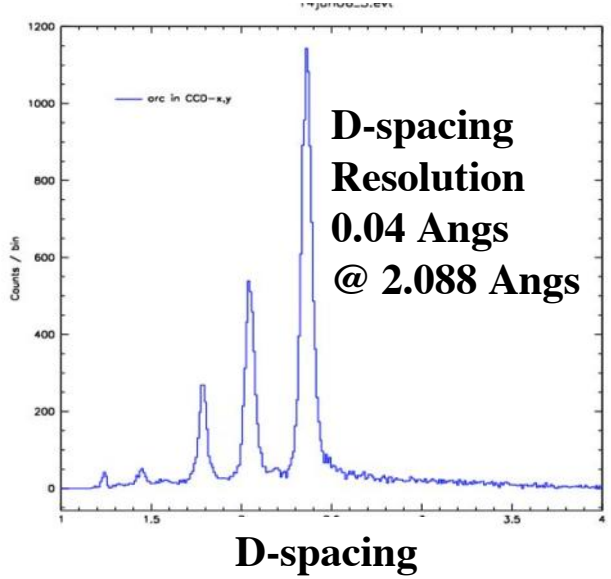
In a plot of energy vs 2Theta we see fluorescence lines as horizontally stretched events. The arcs in this space are due to diffraction and each arc represents a single d-spacing.



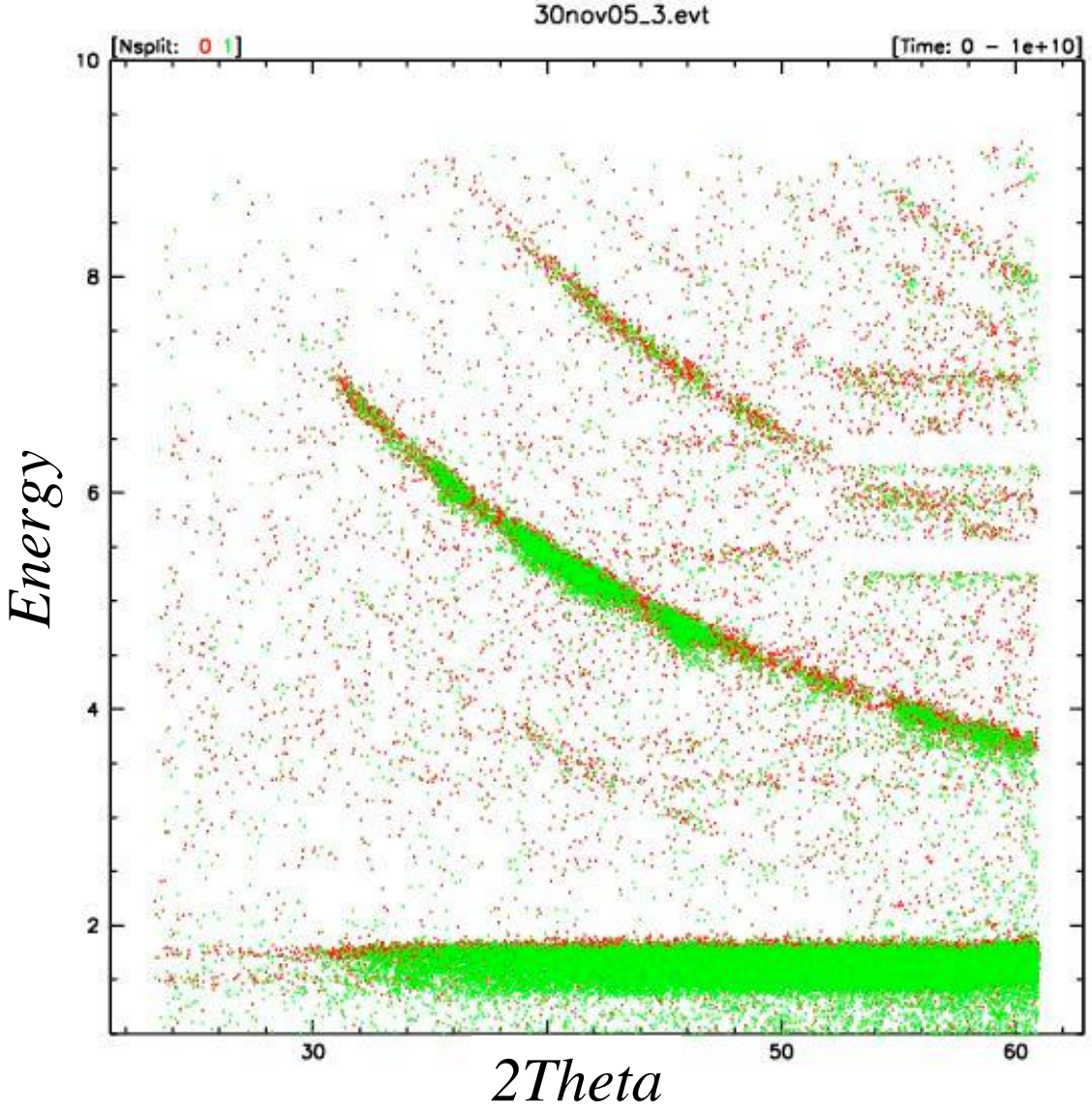


We can convert the energy of each event into a wavelength, take into account the geometry, and convert 2Theta and energy into a d-spacing value for each event using Bragg's Law. Now we can plot an orthogonal space of Energy vs. d-spacing.

The plot directly shows you XRF and XRD information.



Prototype Data



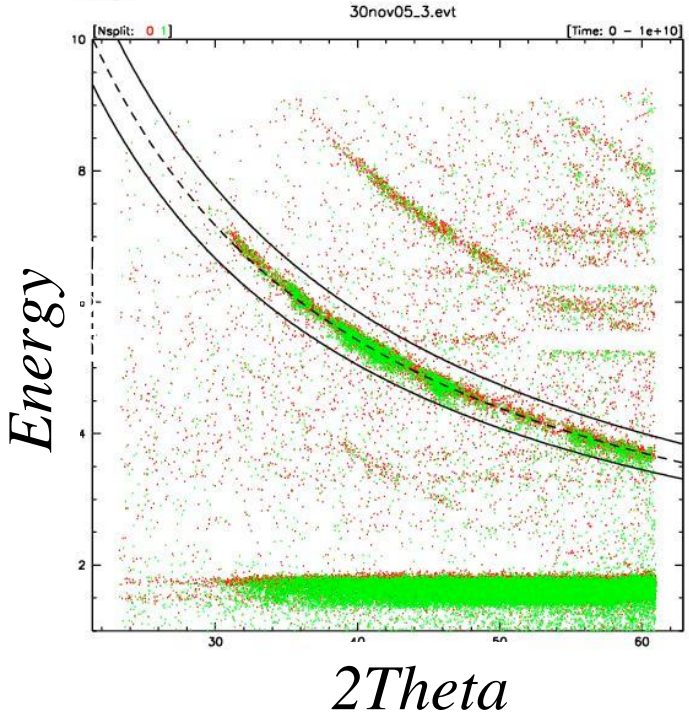
Random Piece of Quartz Found Around Building 2 at GSFC

Clearly see Si Fluorescence And ~10 XRD Signatures.

Note that the arcs are broken up.

GODDARD SPACE FLIGHT CENTER

Prototype Data (Quartz Sample)



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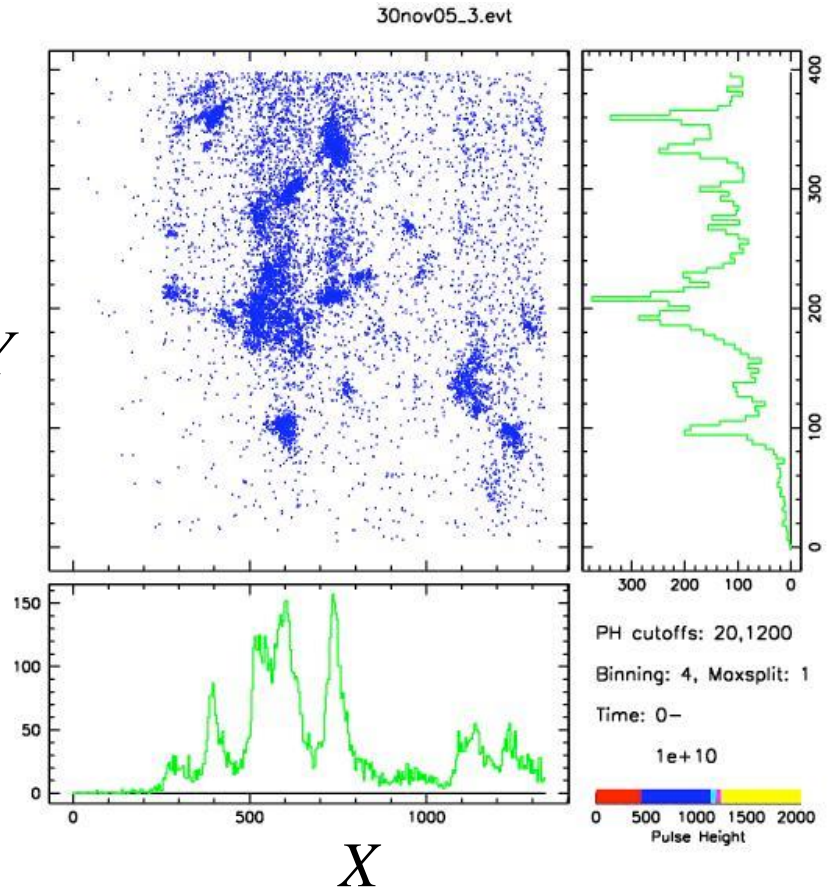


The combination of physical collecting area and broad wavelength coverage with spectroscopy makes the CXRDF insensitive to sample preparation.

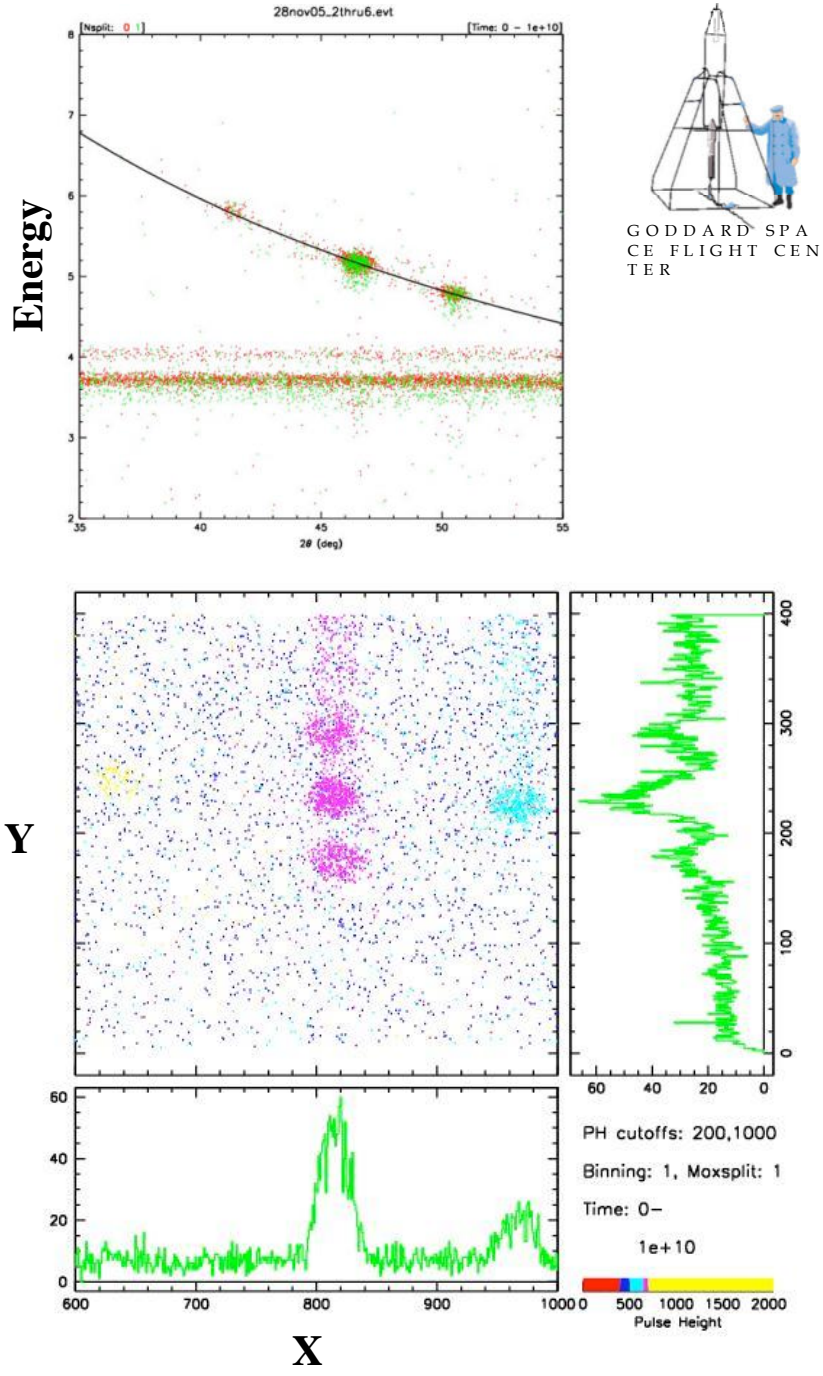
Single Crystal of Calcium Carbonate

Here, we took a single crystal of calcium carbonate and oriented it 5 different ways by tipping and tilting at the sample position.

The image to the lower right shows how the diffracted spot moves around the focal plane. As the image is deflected to the left in the image, the energy of the photons diffracted shifts upward.

The image to the upper right shows that all these points line up on a "constant d-spacing arc" in the energy vs X plane.

A traditional XRD using a single wavelength could not do this.

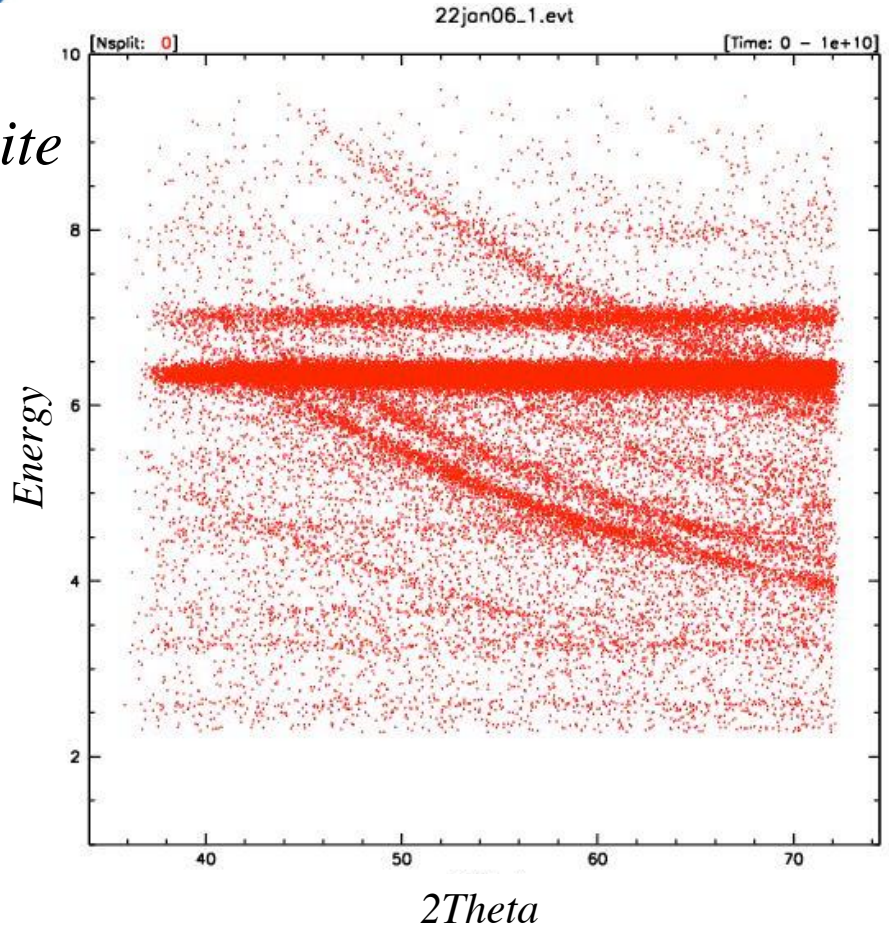


GODDARD SPACE FLIGHT CENTER

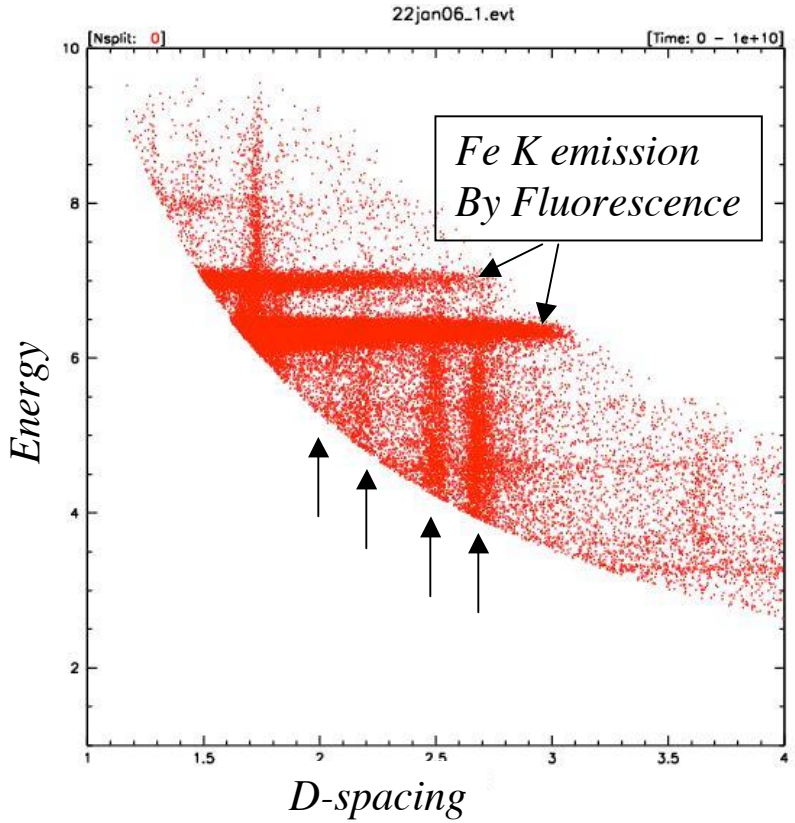
Prototype Data

GODDARD SPACE FLIGHT CENTER

Hematite



Transform event list

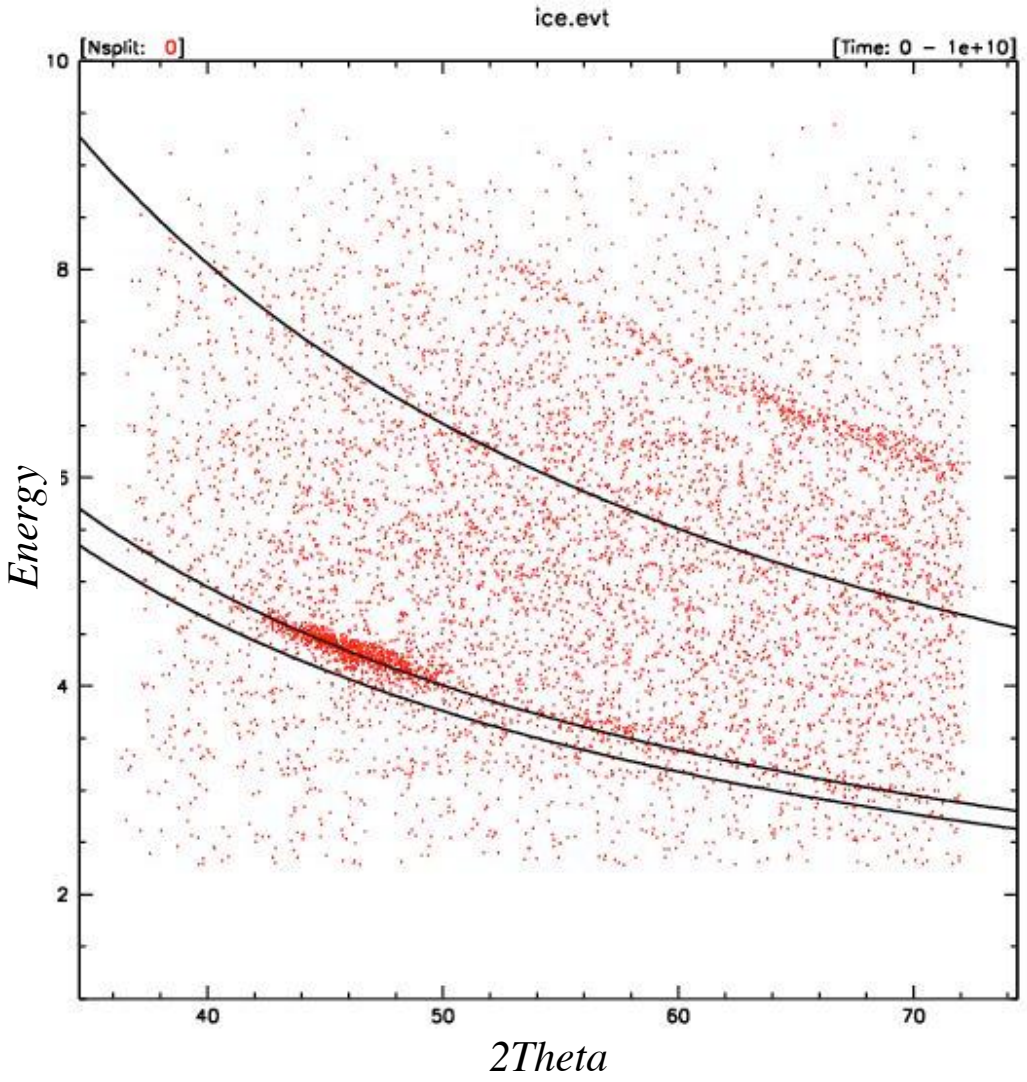


Prototype Data

Water Ice:

1st light water ice with 2nd prototype system

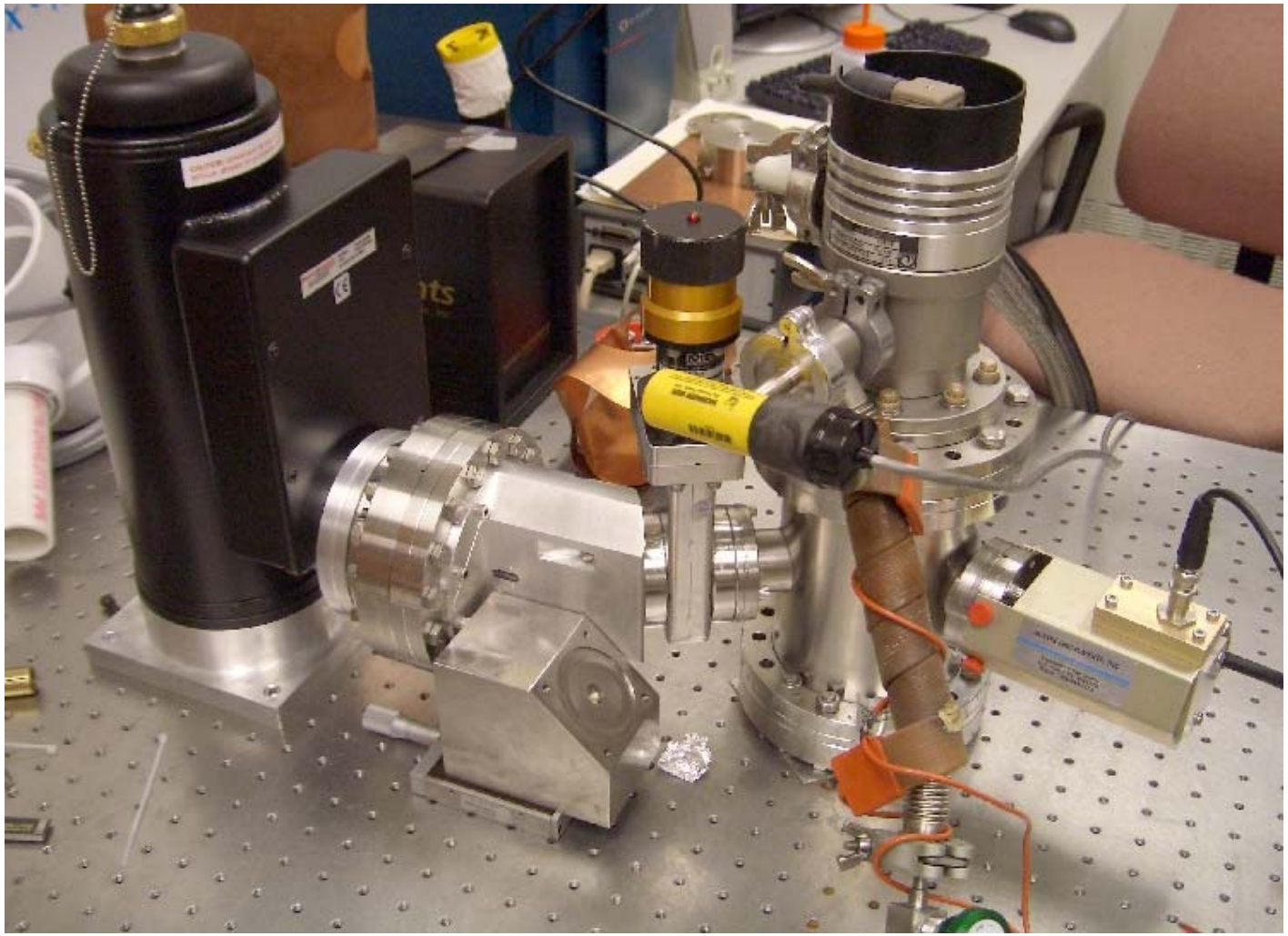
~ 1 minute of data with ice cube pressed up to window

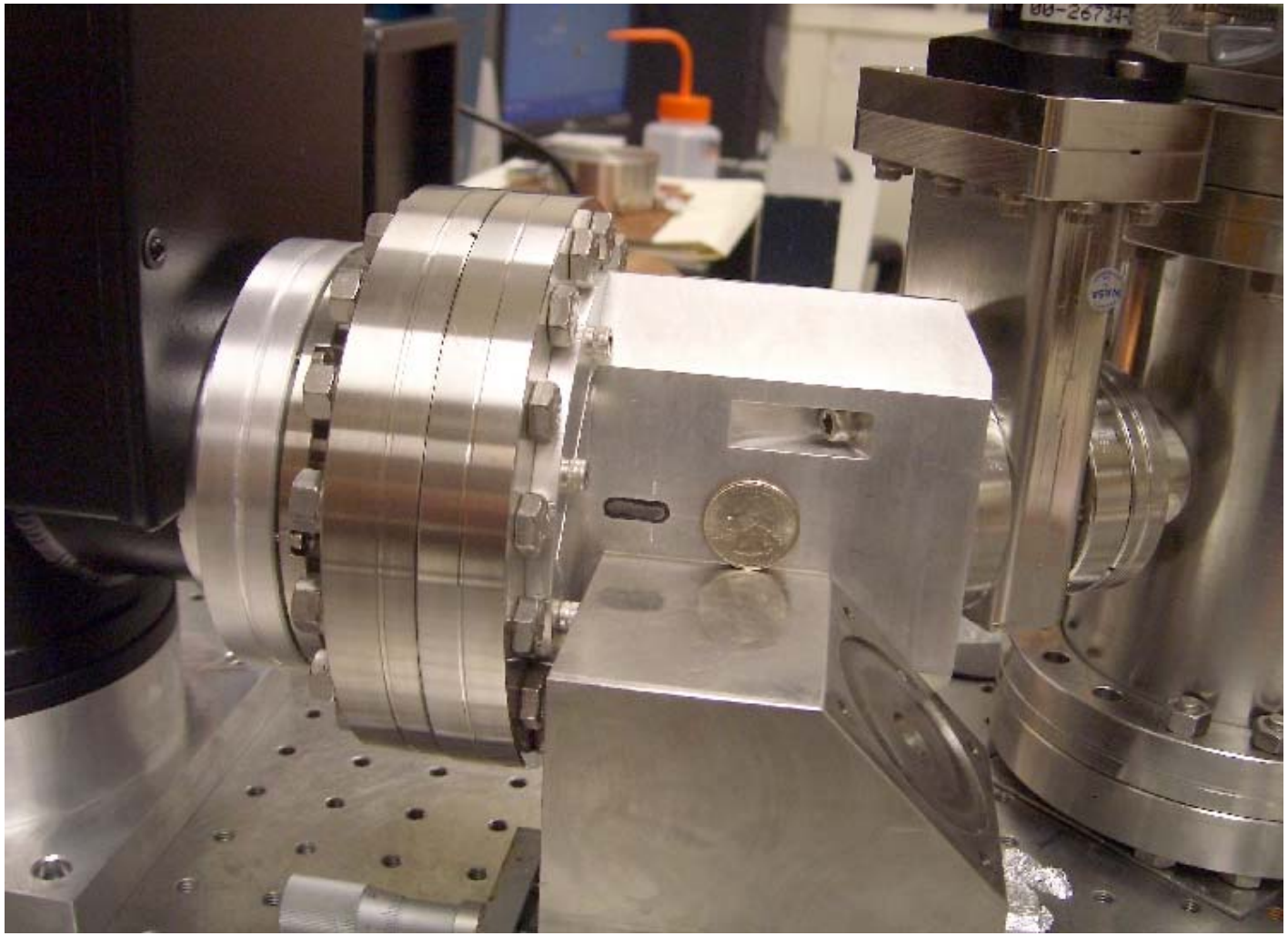


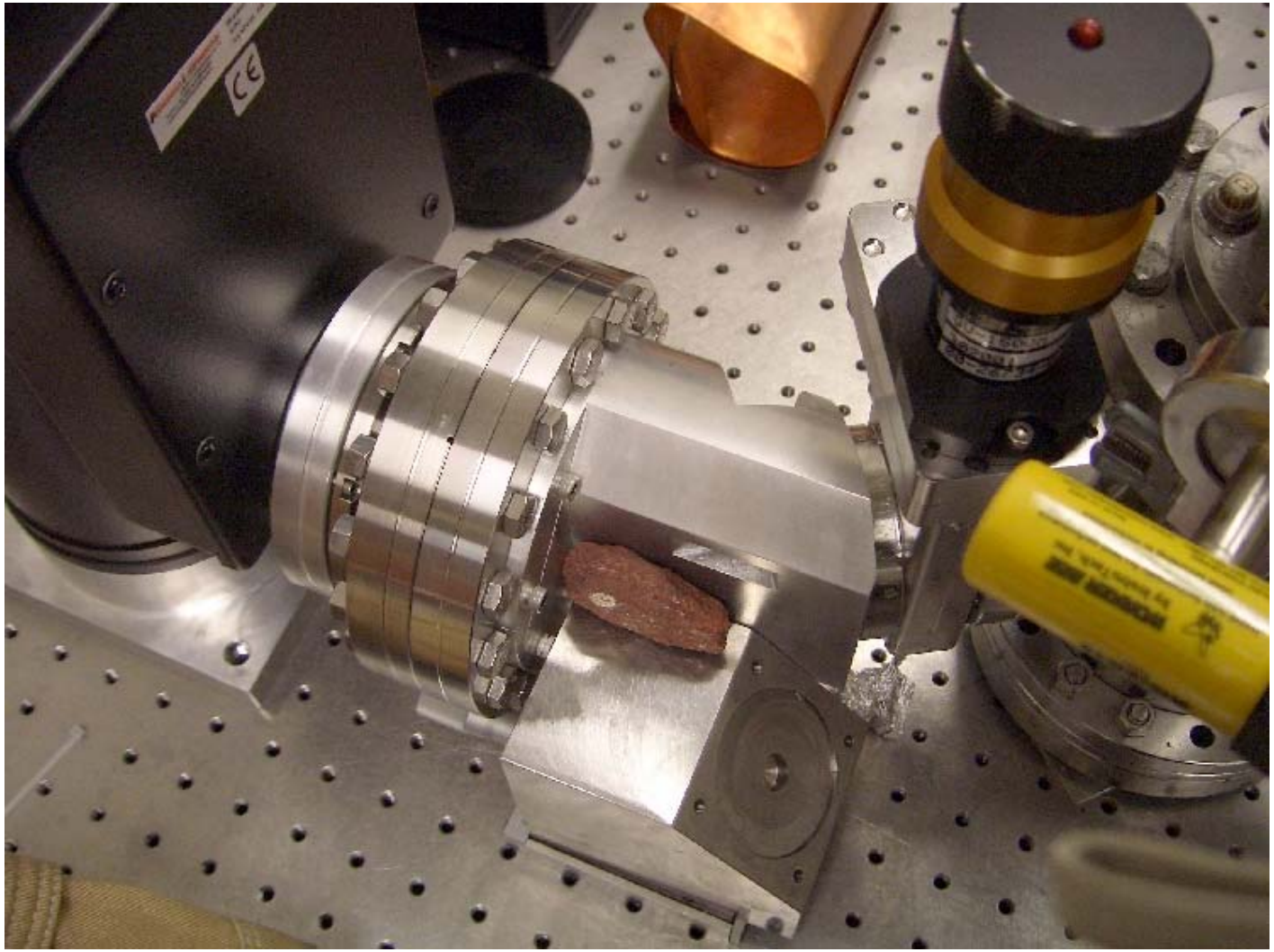
Beryllium Instrument Feature

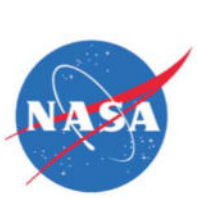
Expected water ice d-spacing arcs

CRREL Next



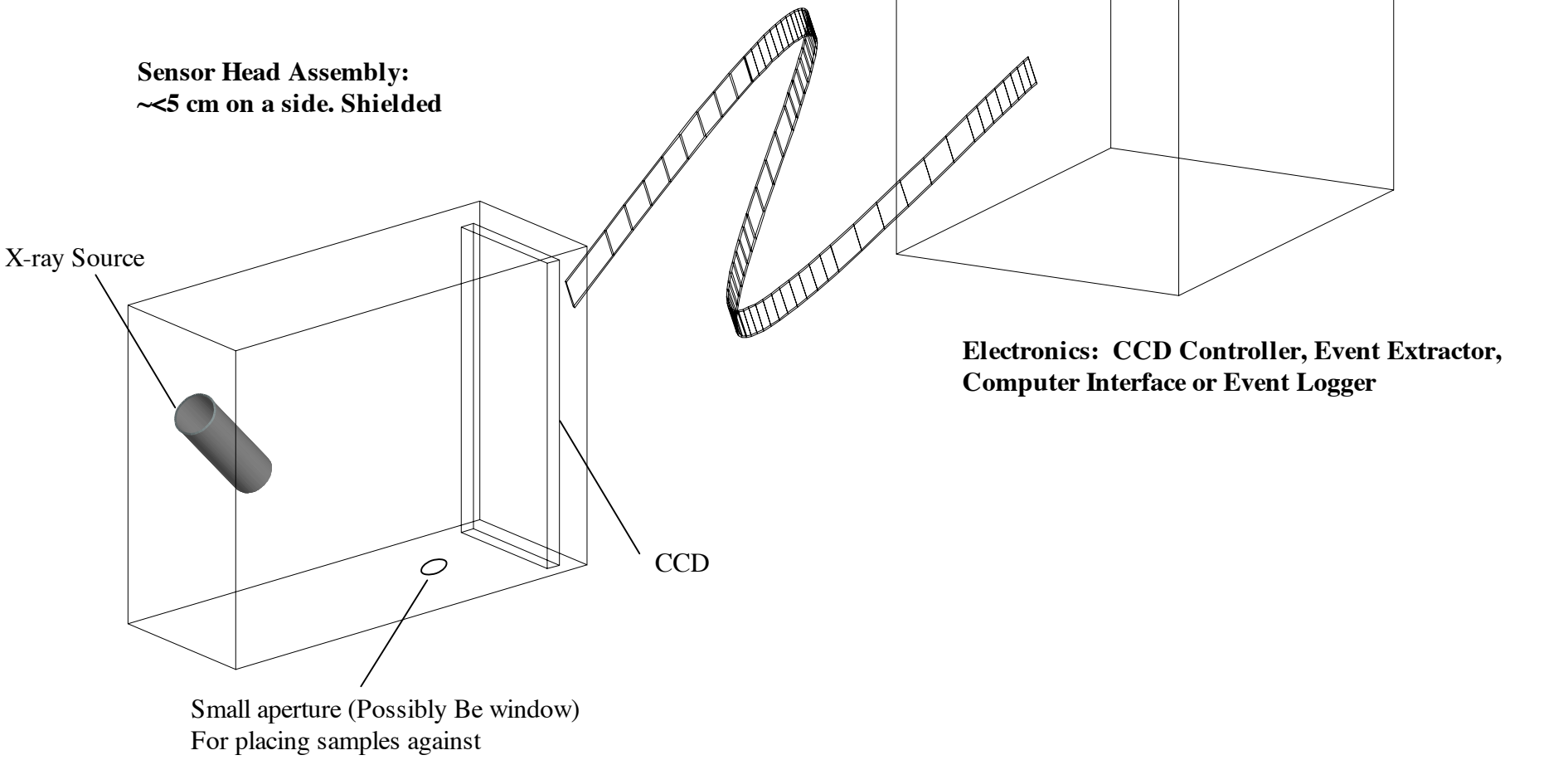




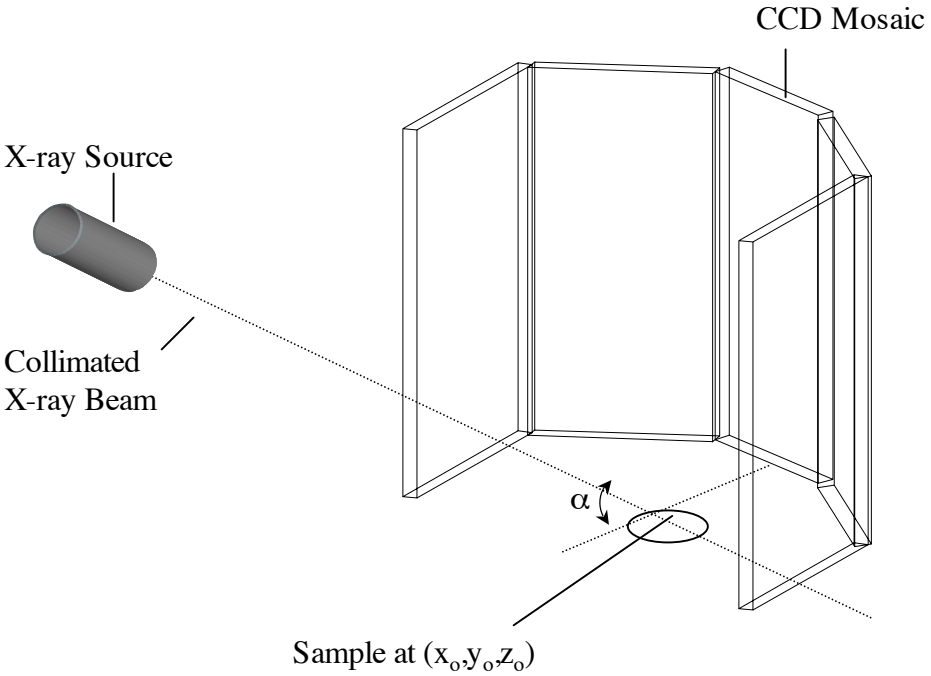


GODDARD SPACE FLIGHT CENTER

Sensor Head Assembly:
~<5 cm on a side. Shielded



Electronics: CCD Controller, Event Extractor, Computer Interface or Event Logger


CCD Mosaic
X-ray Source
Collimated
X-ray Beam
α
Sample at (x$_o$,y$_o$,z$_o$)

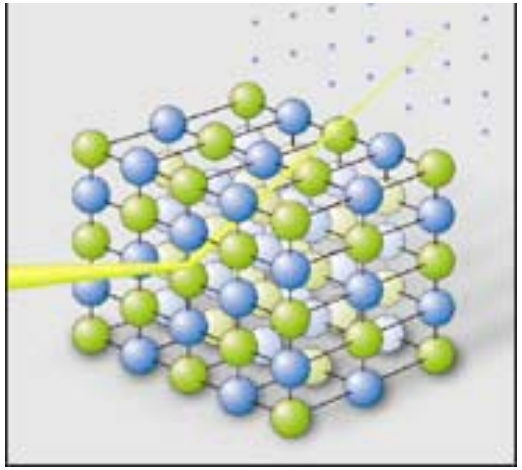
Summary and Status

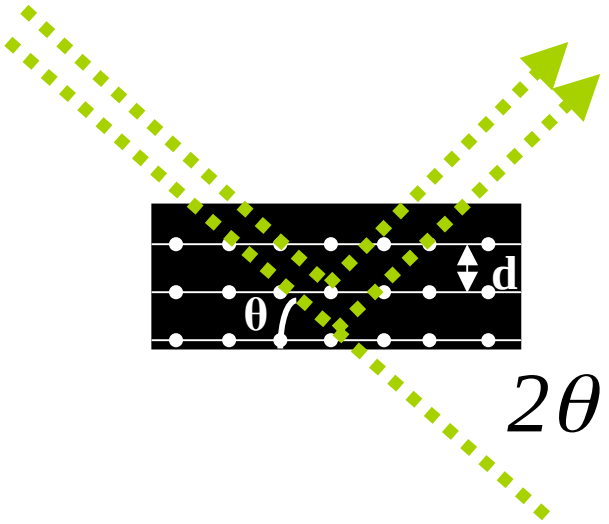
- A material analysis tool that requires no sample preparation and has potential to identify many minerals including water ice.
- Concept is simple
- No moving parts
- Prototype instruments made from commercial components
- Our MIT collaborators have been flying X-ray CCDs for 13+ years
- Estimated Mass/Power for new flight instrument using latest CCD electronic designs: <2 kg ; <2 watts average

Backup

XRD of Crystalline Structures

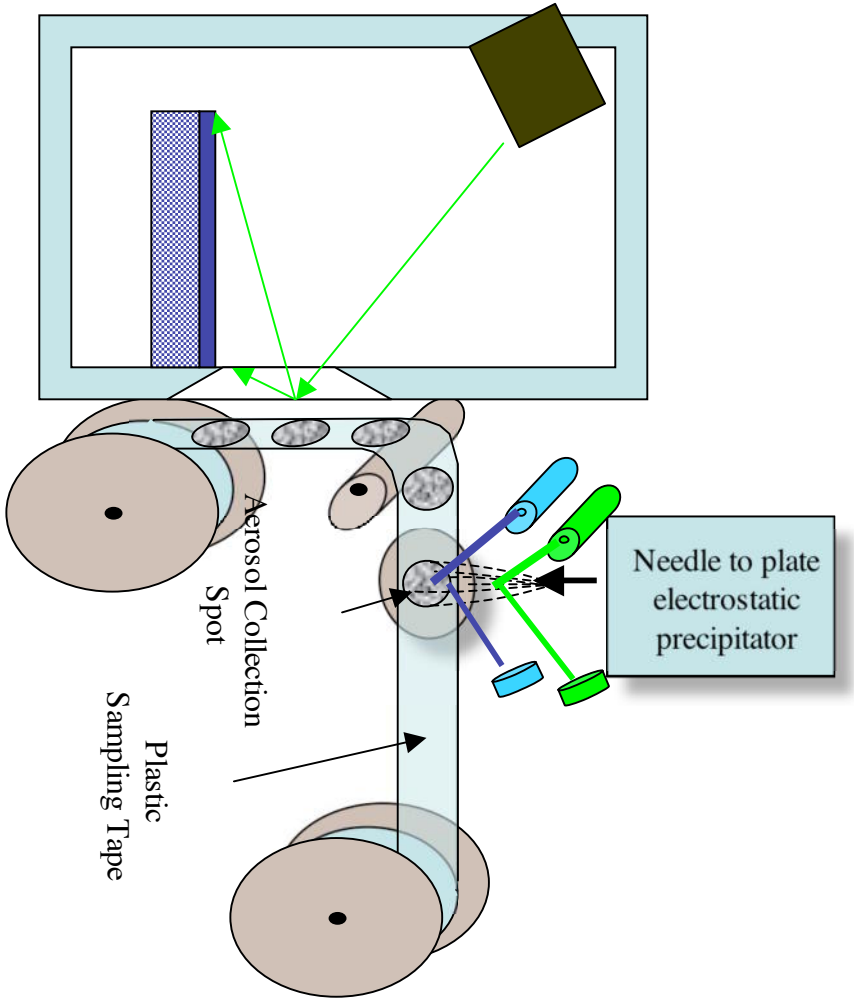
GODDARD SPACE FLIGHT CENTER





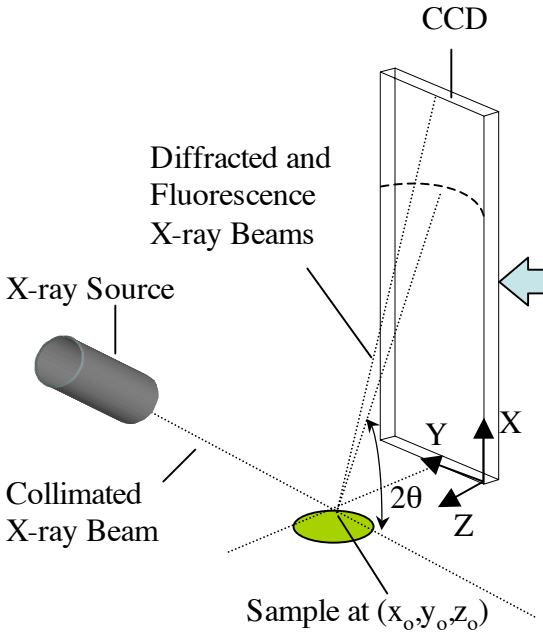
$$n\,\lambda = 2d\sin(\theta)$$

Aerosol Sampling Option



Optical probes for scattering and absorption (provides complementary information on size, refractive indices, etc.)

Instrument Description



CCD Control and Readout Electronics

Computer Interface with Event Processing

4-Dimensional event list:

Time, X, Y, Energy

For each detected X-ray

Apply Geometry

Time, θ, and λ

For each detected event

Apply Braggs Law
n λ = 2d SIN(θ)

Time, d-spacing and energy

For each detected event

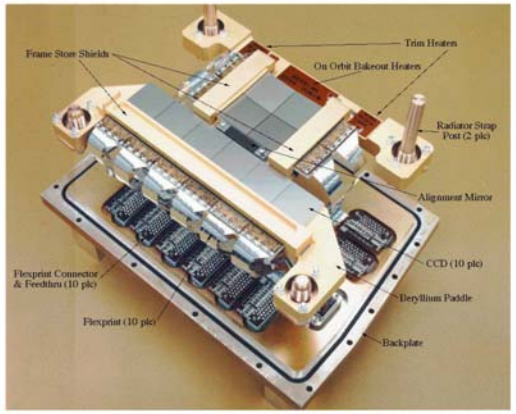
An X-ray Source producing Bremsstrahlung continuum X-rays spanning the 0.1-~10 keV band, sends a collimated beam toward a sample. These X-rays either diffract off the sample or cause characteristic line emission through fluorescence. A photon counting , energy resolving X-ray CCD captures some of these X-rays and produces an event list. This event list can be transformed both fluorescence (elemental composition) and diffraction (mineral atomic-plane spacing) data on an event by event basis.

X-ray Cameras from MIT CCD Group

MIT Center for Space Research has developed and fabricated X-ray cameras and flight electronics optimized for MIT/LL CCDs flown on the ASCA, Chandra, Astro-E, and HETE-2 missions.

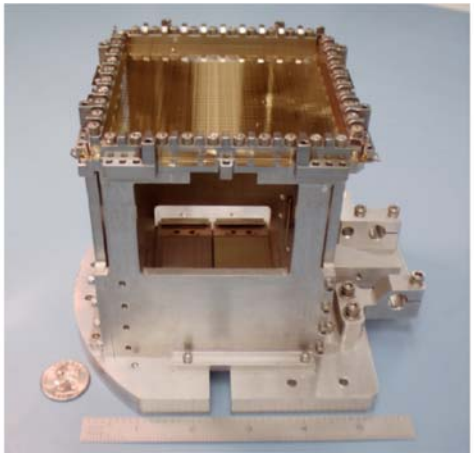
ASCA/SIS (1993)

Chandra/ACIS (1999)



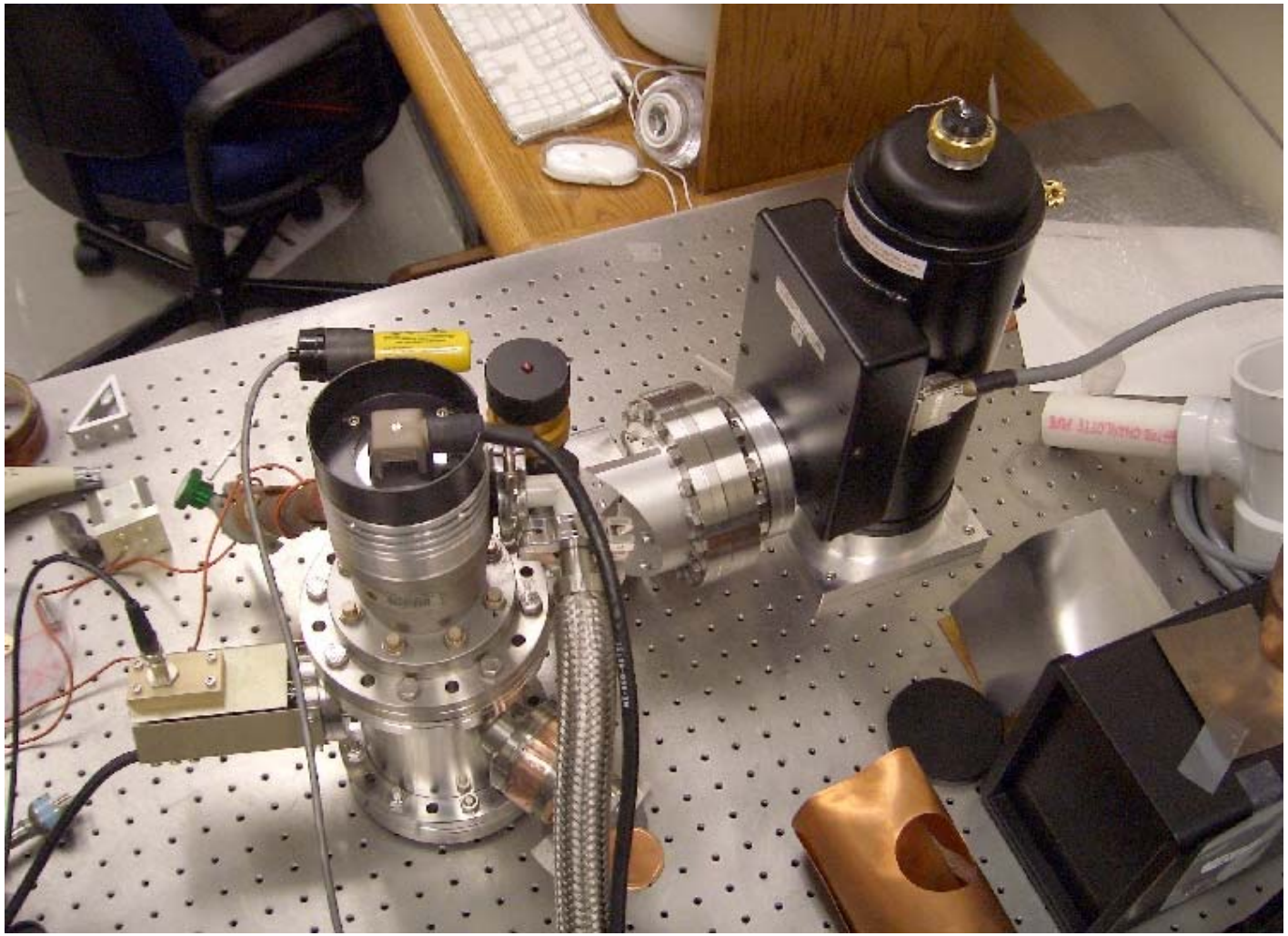
Astro-E/XIS (2000)

HETE SXC (2000)



Application to VSE and Lunar Exploration

- Definitive Identification of Minerals
  - Definitive Identification of Water-Ice
- Could Provide Insight into Lunar History via Analysis of structure of the d-spacings and particle/grain size, shape, and orientation distributions



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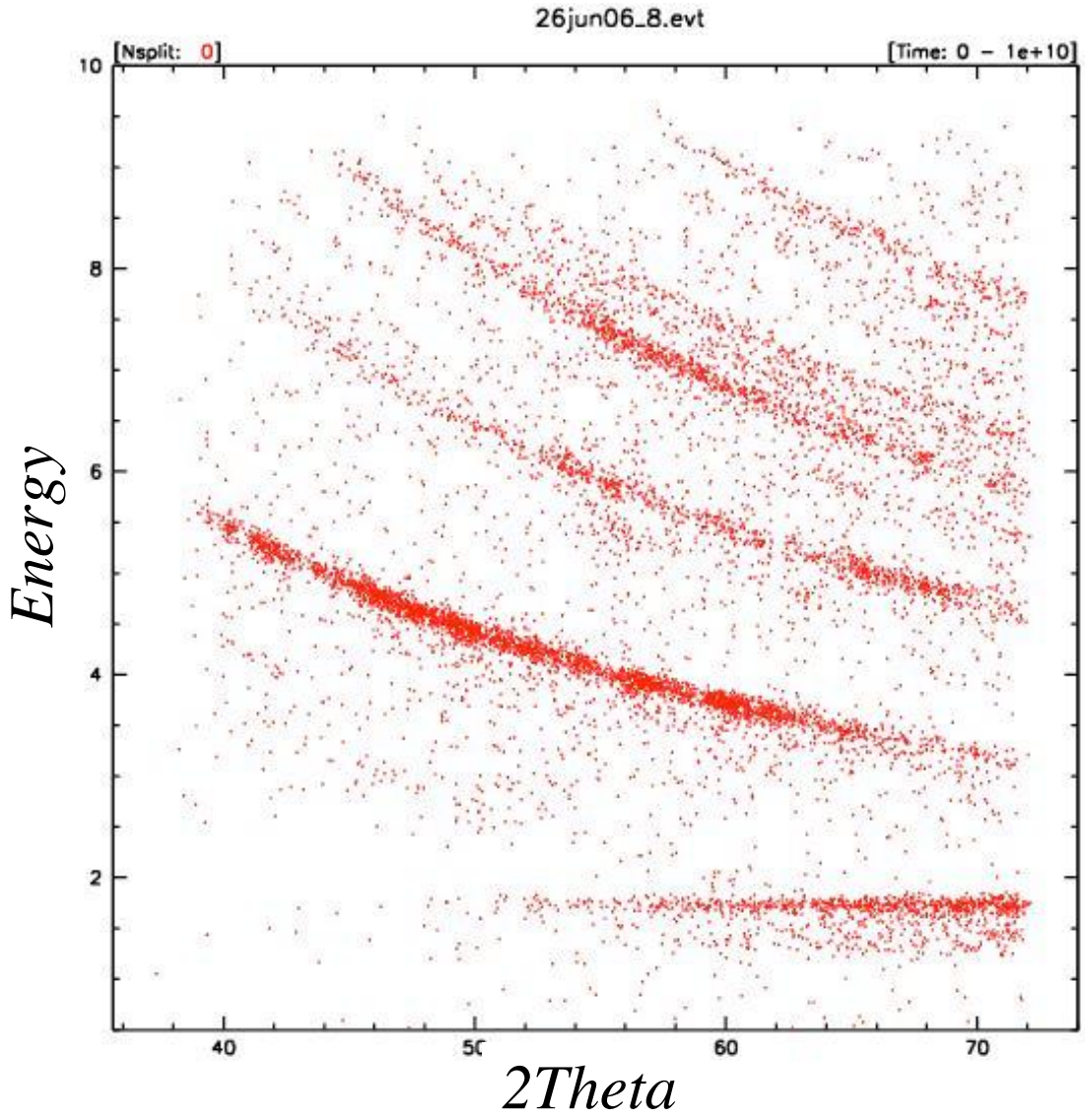

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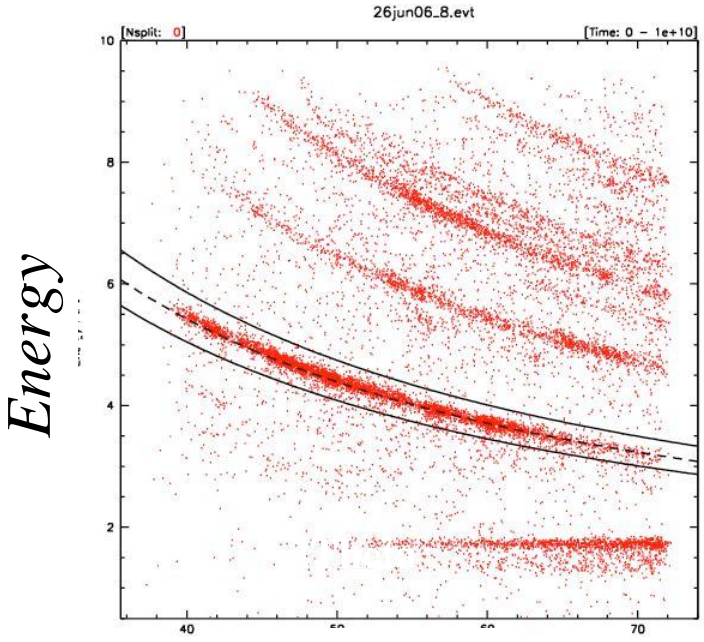

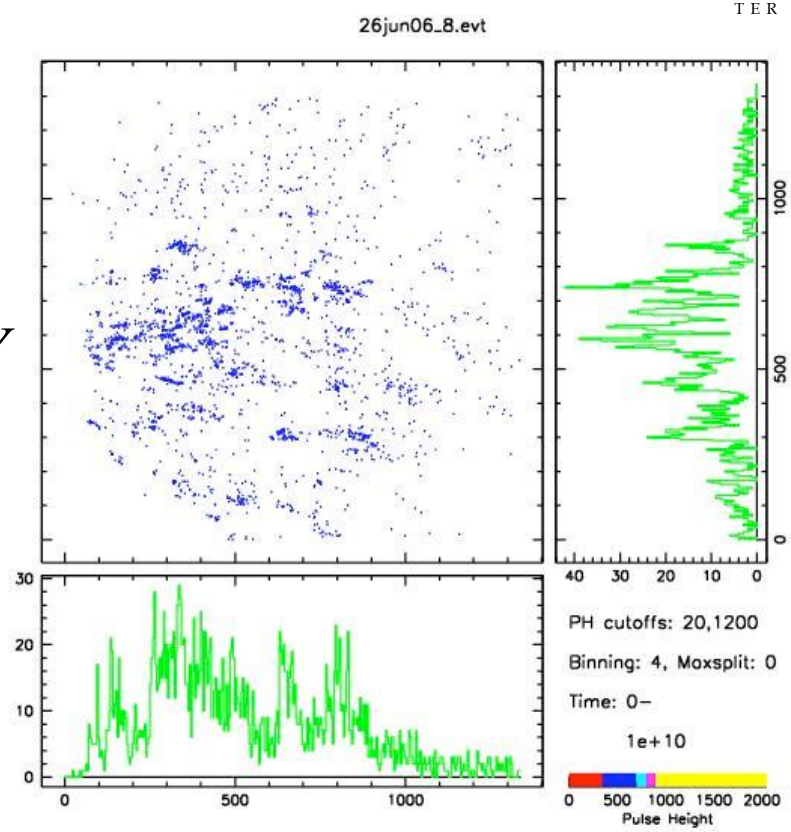

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